THE TEMPERATURE COEFFICIENT OF THE RATE OF CONTRACTION OF THE DORSAL BLOOD-VESSEL OF THE EARTHWORM.

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Certain unpublished criticisms of a previous paper of the senior author[2] have led us to make a further investigation of the effects of changes of temperature upon the rate of contraction of the dorsal blood vessel of the earthworm. The criticism offered against the previous work was that no evidence was presented to show that the temperature of the forms studied, worms and fish-embryos, was the same as that of the water in which they were immersed. The force of the criticism is recognized, and we are now able to present the results of an investigation in which the temperature of the worm studied was determined by means of a delicate clinical thermometer inserted in the long, tubular, alimentary canal of the worm.

We are now publishing under another title[3] an account of the work in which it is shown that the temperature of the surrounding water does furnish an excellent indicator of the inner body temperature of the earthworm, when this animal is immersed in water for experimental purposes. Inasmuch as this is true we have no doubt that the previous work upon *Nereis*, *Tubifex*, and the embryos of *Fundulus* and the toad-fish will bear the same sort of inspection.

We will not at this time take up any discussion of the literature of the subject. The papers of Snyder, Robertson, Loeb and Ewald and others are available for examination. The formula employed for the computation of the temperature coefficients

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[2] Rogers, Charles G., "Studies Upon the Temperature Coefficient of the Rate of Heart Beat in Certain Living Animals," *American Journal of Physiology*, 1911, Vol. XXVII., pp. 81–93.

[3] Rogers, Charles G., and Lewis, Elsie M., "The Relation of the Body Temperature of the Earthworm to that of its Surroundings," BIOLOGICAL BULLETIN, 1914, Vol. XXVII., pp. 261–267.

is the one used by Snyder in all his work, and concerning which he has presented some matters of historical interest,[1]

$$Q_0 = \left(\frac{K_1}{K_0}\right)^{\frac{10}{T_1 - T_0}}.$$

The material used in this study was the large earthworm, *Lumbricus agricola*. This form presents two desirable features for this work; 1st, the animals are not by nature restricted to any definite or narrow limits of temperature at which their normal physiological processes take place; and 2d, it is well adapted structurally for the work in that it is easily possible to place a delicate temperature measuring apparatus in the alimentary canal, and it is also easy to see the contractions of the dorsal blood vessel through the more or less transparent body wall. This last fact is of special importance as it makes it practicable to leave the animal undisturbed in its constant temperature bath, thus obviating any disturbance of the vascular contractions through nervous action due to stimulation from without.

Methods.

As a preliminary to the actual temperature work a number of worms were subjected to immersion, for varying periods, in water to ascertain what harmful effects might result. Without going into detail as to this work it may be stated that the worms are able to withstand immersion in tap water for a sufficient time to allow all the experimentation needed for the temperature studies, without showing any harmful effects. In fact certain worms have been immersed for as long a period as two weeks without showing any injurious effects.

The temperatures of the worms were regulated, then, by placing them in baths of water, the temperature of which was controlled by placing the dishes in thermostats having practically constant temperatures, in refrigerators cooled by ice, or in the running water of the laboratory, which was found to have a very constant temperature.

The temperatures of the worms were determined by means of

[1] Snyder, C. D., "On an Interpolation Formula Used in Calculating Temperature Coefficients for Velocity of Vital Activities, Together with a Note on the Velocity of Nerve Conduction in Man," Science, N.S., Vol. XXXIV., No. 874, p. 415.

delicate clinical thermometers, in the form of thermo-couples, which could be inserted into the mouths of the worms and pushed on down into the stomach intestine. These thermo-couples were made of No. 32 copper and No. 32 constantan wires. Any difference in the temperature of the two junctions of the couple sets up an electromotive-force proportional in its strength to the amount of the temperature difference, and which can be accurately measured by means of a delicate galvanometer. In this particular work it was found that 1° C. was represented by a shift in the reading of the galvanometer scale of about 16 mm. As it was practicable to read to half millimeters it will be seen that a temperature difference of 0.03° could be determined. For a somewhat more detailed account of the method of temperature measurements the reader is referred to another paper.[1]

The worm having been subjected to a given temperature for a sufficient length of time to have become completely adjusted to the new condition, the temperature of the worm was noted, and the length of time required for a definite number of beats of the dorsal blood-vessel, usually 25, was taken by means of a stop-watch reading to fifths of a second. The worm was then changed to another bath at a different temperature, allowed to remain long enough to become thoroughly adjusted to the new condition, and another reading of the rate of contraction of the dorsal blood vessel made. From the data thus obtained the temperature coefficient of the rate of contraction was calculated by means of the formula referred to above.

It may be said that all possible precautions were taken to avoid serious errors in the work. Temperatures were determined by making the readings of the galvanometer against a certified thermometer calibrated to tenths of a degree C. The temperatures of the various baths were kept as uniformly constant as possible and the exact temperature taken each time a count was made. Occasionally one is in doubt as to whether a contraction of the dorsal blood vessel has actually taken place. In such a case the reading was thrown out and another made so as to make sure of the fact. The temperature of the room was kept as constant as possible in order to avoid any changes of resistance

[1] Rogers, Charles G., and Lewis, Elsie M., *l. c.*

in the copper wires and in the galvanometer which might tend to disturb the results. Manipulation of the worms was reduced to a minimum in order that nervous effects might not be introduced to invalidate the temperature effects. Reading of the rates of contraction of the dorsal blood vessel before and after the insertion of the glass covered junction indicated that the mere insertion of the instrument in the alimentary canal made no difference with the rate.

TABLE I.

No. of Worm.	K_1	K_0	T_1	T_0	Q_{10}
3	19.35	13.74	21.43°	11.60°	1.406
5	15.00	9.80	18.00°	11.50°	1.925
6	20.35	10.90	18.00°	11.50°	2.593
7	21.10	13.80	16.04°	11.50°	2.548
8	15.72	8.92	16.04°	11.50°	2.096
9	22.00	9.93	16.04°	11.50°	5.766
10	16.93	10.60	16.04°	11.50°	2.805
11	17.75	11.29	16.04°	11.50°	2.642
12	14.79	11.76	16.04°	11.50°	1.656
14	27.00	19.40	26.40°	11.70°	1.272
16	26.90	14.92	26.40°	11.60°	1.485
17	15.27	11.13	26.50°	11.60°	1.236
18	19.70	15.33	26.50°	11.60°	1.176
19	29.30	12.50	27.13°	12.55°	1.793
21	24.15	13.50	27.12°	12.55°	1.280
24	33.60	24.00	27.00°	16.36°	1.372
26	37.80	26.70	26.60°	24.60°	5.754
27	32.56	19.35	20.00°	9.50°	2.044
28	35.27	24.55	20.00°	9.50°	1.413
29	21.39	8.85	27.50°	14.00°	1.621
30	28.20	12.13	27.10°	14.00°	1.899
31	20.40	13.18	27.70°	14.00°	1.365
32	27.48	11.75	27.30°	14.04°	1.898
33	21.50	12.66	26.50°	14.02°	1.525
34	26.55	14.05	25.60°	14.03°	1.733
35	22.00	12.95	25.08°	13.88°	1.605
36	24.86	12.63	25.08°	13.92°	1.838
37	16.97	8.95	22.54°	13.95°	2.109
38	20.40	11.58	22.46°	13.96°	1.947
39	22.43	11.86	21.86°	13.94°	2.236
40	21.59	9.81	21.43°	13.95°	2.871
41	26.80	11.16	22.90°	13.72°	2.603
42	21.97	11.10	22.95°	13.74°	2.099
43	23.33	11.94	22.71°	13.80°	2.121
44	25.00	11.23	23.18°	13.73°	2.388
Average value of temperature coefficient for all specimens.......					2.173

The preceding table, Table I., gives the data derived from the actual experiments and also the values of the temperature coefficient calculated from the data. In the tables the letters

K_1 and K_0 indicate the rates in contractions per minute at the temperatures T_1 and T_0 respectively, in degrees Centigrade.

If we arrange the data of Table I. so as to show the relation existing between the higher and lower temperature ranges and the value of Q_{10} we have evidence that for the lower temperatures there is a higher coefficient than for the higher ranges. This fact is not so clearly shown in the case of the earthworm as in some of the forms already studied, probably for the reason that it is very difficult to count the beats of the dorsal blood vessel of the earthworm at temperatures below 8° C. The movements of the walls are so feeble and so slow that one is not sure when a contraction has taken place.

TABLE II.

T_1.	T_0.	Number of Worms.	Average Q_{10}.
About 27°	to about 14°	4	1.671
" 27°	" " 12°	2	1.536
" 26°	" " 11°	4	1.292
" 25°	" " 13°	3	1.725
" 22°	" " 13°	6	2.199
" 21°	" " 13°	2	2.533
" 20°	" " 9°	2	1.728
" 16°	" " 11°	6	2.919

In Table II. we have such an arrangement of the data as suggested in the preceding paragraph. It will be noted that while in general the coefficients for the lower ranges are higher than those for the higher ranges of temperature, there are very marked exceptions to the rule. The only explanation we have to offer at this time for the rather marked variation from what we should expect, if the beat of the dorsal blood vessel of the earthworm is subject to the same laws as the beats of various hearts already studied, is that we have here to deal with a series of nervous effects which must be in some way eliminated in order to avoid complications. Up to the present time we have not found any means of avoiding these nervous effects in the worm, though in fish embryos where the rate of heart beat was studied before the nervous connections were established it was found that one could predict with some degree of certainty what the rate of heart contraction should be at any stated temperature.

That the rate of beat of the dorsal blood vessel of the earthworm is to some extent under the control of the nervous system will be shown in another publication from this laboratory.

It is to be noted also that the temperature coefficient of the rate of contraction of the dorsal blood vessel of the earthworm is, for the temperatures at which the worm would naturally live, of the same general magnitude as those of chemical reactions, and the average for the whole series, 2.173, also falls within the limits usually set for the temperature coefficients of such reactions. We have no reason, as yet, to assign for the much reduced coefficients for the higher temperature ranges.

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